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[redacted] 25X1

February 6, 1956

[redacted] 25X1

Subject: Ferrite Antenna Development
[redacted] 25X1

Dear Sir:

Pursuant to recent discussions between representatives of your Agency and [redacted], we are pleased to submit herewith our quotation for a program of development of ferrite antennas. 25X1

The complete 9 month program proposed has been divided into two phases. During Phase A effort will be concentrated on the design and construction of 30 antenna-detector units. Phase B will consist of an investigation of the feasibility of a broadband ferrite antenna for the range 3-30 MC. Complete details on the program are contained in our technical proposal entitled "Ferrite Antenna Development", [redacted] 25X1 [redacted] 25X1 three copies of which are enclosed. This technical proposal is considered to be a part of this quotation.

This program will be conducted by the [redacted] 25X1 [redacted] 25X1. This group is particularly well qualified to undertake the program both because of their past work on related projects and due to the excellent facilities which are available in the laboratory. In addition, close coordination between other groups within [redacted] 25X1 and elsewhere in the company will make the latest solid state materials available to the project personnel.

Our total estimated selling price for the 9 month program outlined in the technical proposal is $47,330.43 on a cost-plus-a-fixed-fee basis, inclusive of fixed fee. A breakdown of this total is attached as Appendix A to this letter.

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Since a Master R&D contract is presently being negotiated with your Agency, we assume that the program proposed will be added as a specific task under this contract, assuming successful negotiation of mutually agreeable terms and conditions. Accordingly, we request that the task order when issued be modified to provide that the work will be conducted for a period of nine months beginning April 1, 1956 rather than indicating that the work is to be completed on a specific date. While we recognize the necessity for indicating a specific date on which expenditures under the task order must be concluded, the nature of the work to be carried on does not permit a completion date as such to be specified.

Because of limitations on the continued availability of the technical personnel and facilities involved, this quotation will expire 30 days from the date of this letter. We would be pleased, however, to discuss an extension of this period if circumstances permit at the time.

If we can be of further assistance, please contact the undersigned at your convenience.

Very truly yours,

[redacted] 25X1

Attachment

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PROPOSAL FOR FERRITE ANTENNA DEVELOPMENT

[redacted] 25X1

January 1956

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1. SUMMARY

A ferrite antenna development program is proposed consisting of two phases extending over a 9-month period.

The initial phase consists of the design, construction, and delivery of 30 units, each unit comprised of a ferrite antenna and detector suitable for operation into a small audio amplifier. Twenty of the thirty units are to be narrow band, approximately 5 mcs in width, and tunable over a calibrated spectrum of 50 to 200 mcs. The remaining 10 units are to be broadband covering the 50 to 250 mcs spectrum without tuning. The antenna designs are to be based principally upon existing knowledge and techniques.

The second phase of the proposed development program is the investigation of the feasibility of a broadband ferrite antenna covering the frequency spectrum from 3 to 30 mcs. The investigation is to consist of a theoretical analysis of the gain-bandwidth product of a ferrite antenna and a supporting materials measurement program.

The proposed ferrite antenna development program will be undertaken by the [redacted] will result in a wide coverage of the solid state field and will make the latest solid state materials available to the program.

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2. **PHASE A:** A Proposal for the Design and Construction of 30 Antenna - Detector Units

I. Introduction

A small ferrite antenna in conjunction with a crystal detector can serve as a compact, portable device to detect the presence of electromagnetic radiation. The antenna and detector are intended to drive an audio amplifier. The output from the amplifier would provide certain information concerning the modulation of the fields. Unless the antenna were narrow band, no information concerning the radiating frequency would be available. If the antenna were narrow band, however, the frequency of the radiating fields could be determined to an accuracy of approximately one bandwidth with some additional allowance if operation is at other than room temperature plus or minus 20 degrees.

The experience, acquired by [redacted] 25X1
[redacted] during the development of [redacted] makes a small size 25X1
broadband ferrite antenna available for use as an electromagnetic radiation detector 25X1
over the frequency spectrum from 50 to 250 mcs. Although no major design work is anticipated, it should be noted that the behavior of the [redacted] was not studied 25X1
from [redacted] 25X1
[redacted] The behavior of the antenna throughout the entire 50 to 250 mcs 25X1
frequency band will need to be measured.

The design of a narrow band tunable antenna can be expected to require more developmental work than the broadband antenna, since the knowledge gained during the development of the wide band ferrite antenna is not directly applicable to the design of a narrow band antenna. There is speculation that the material itself is responsible for the broadband characteristic of the ferrite antenna. If such were the case, either a sufficiently narrow band material or an external narrow band filter would be needed. If the ferrite were not responsible for the wideband behavior, a major redesign of the antenna would be required.

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A bandwidth of no more than 5 - 10 mcs is needed if the antenna is to give a useful frequency resolution as a radiation detector. The desired tunable frequency band is 50 to 250 mcs. It will not be a simple problem to achieve such a narrow band antenna tunable over so large a range. Consequently, a considerable amount of design and development is to be expected before the tunable, narrow band antenna can be fabricated.

The testing and calibration of the antennas pose a problem of another sort. Licensing of experimental transmitters in the 50 to 250 mcs region is severely restricted by the FCC. Assistance by the contracting agency may be necessary to procure the required licenses for a prompt completion of the program.

II. Proposed Program for the Design and Construction of 30 Antenna-Detector Units

(a) 20 Narrow Band Tunable Units

It is proposed to build 20 tunable, narrow band antenna-detector units. Each unit is to have a bandwidth of approximately 5 - 10 mcs and is to be tunable over the region from 50 to 250 mcs. The units will be designed for operation into a single-ended, high impedance audio amplifier. The size of each unit is approximated to be 6" x 2" x 2". Several forms that the narrow band antenna might assume are sketched in Figures 1 through 3.

Figure 1 is inherently a broadband antenna whose narrow band characteristic is achieved by means of a separate tunable, narrow band-pass filter. The ferrite antenna itself, exclusive of the band-pass filter, will as presently conceived also form the basic element of the wideband antenna to be described later.

If one antenna cannot give the desired coverage, then several similar antennas might be used, each moderately narrow band. The tunable high pass filter thereby would not be required to tune over as large a range of frequencies. Figure 2 indicates the possible form of such an antenna.

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Figure 3 shows an antenna whose narrow band property is designed into the antenna proper. The antenna is tuned by moving the ferrite core relative to the coil. Such an antenna might have a storage length of 6", but increase in overall length to 12" as it is tuned.

(b) 10 Wideband Units

It is also proposed to build ten wideband antenna-detector units based upon the design of the currently available [redacted] ferrite antenna suitable for operation over the 50 to 250 mcs region. The anticipated size of the unit is approximately 6" x 1-1/2" x 3/4". The unit will be designed for operation into a single-ended high impedance audio amplifier. A possible design is sketched in Figure 4.

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(c) Reports

Monthly progress letters and a final instruction booklet will be prepared for the contracting agency to report on the work done in Phase A.

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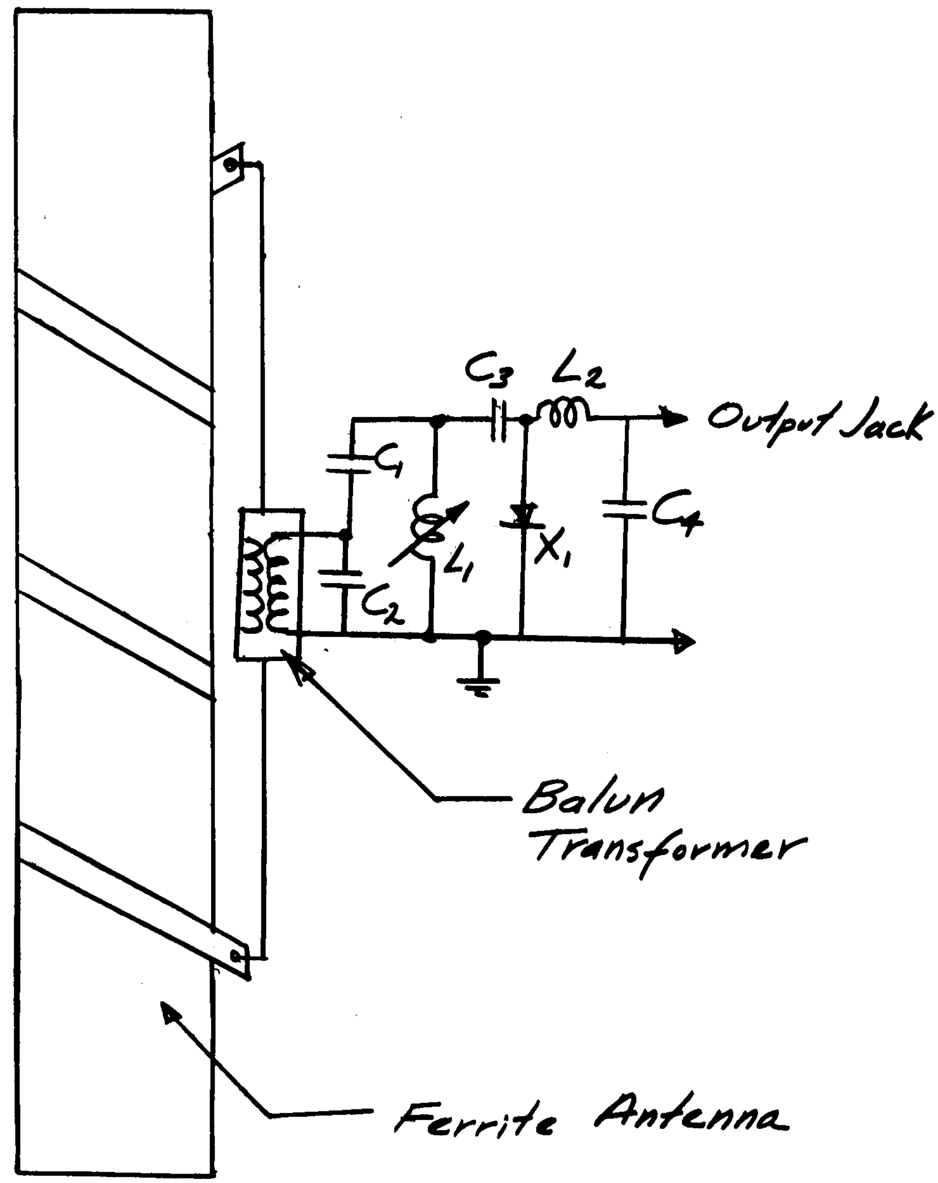

FIGURE 1

NARROW BAND UNIT

C_1	3 μμf	Typical Values
C_2	5 μμf	
C_3	3 μμf	
X_1	Crystal Detector	
L_1	Tuning Inductor	

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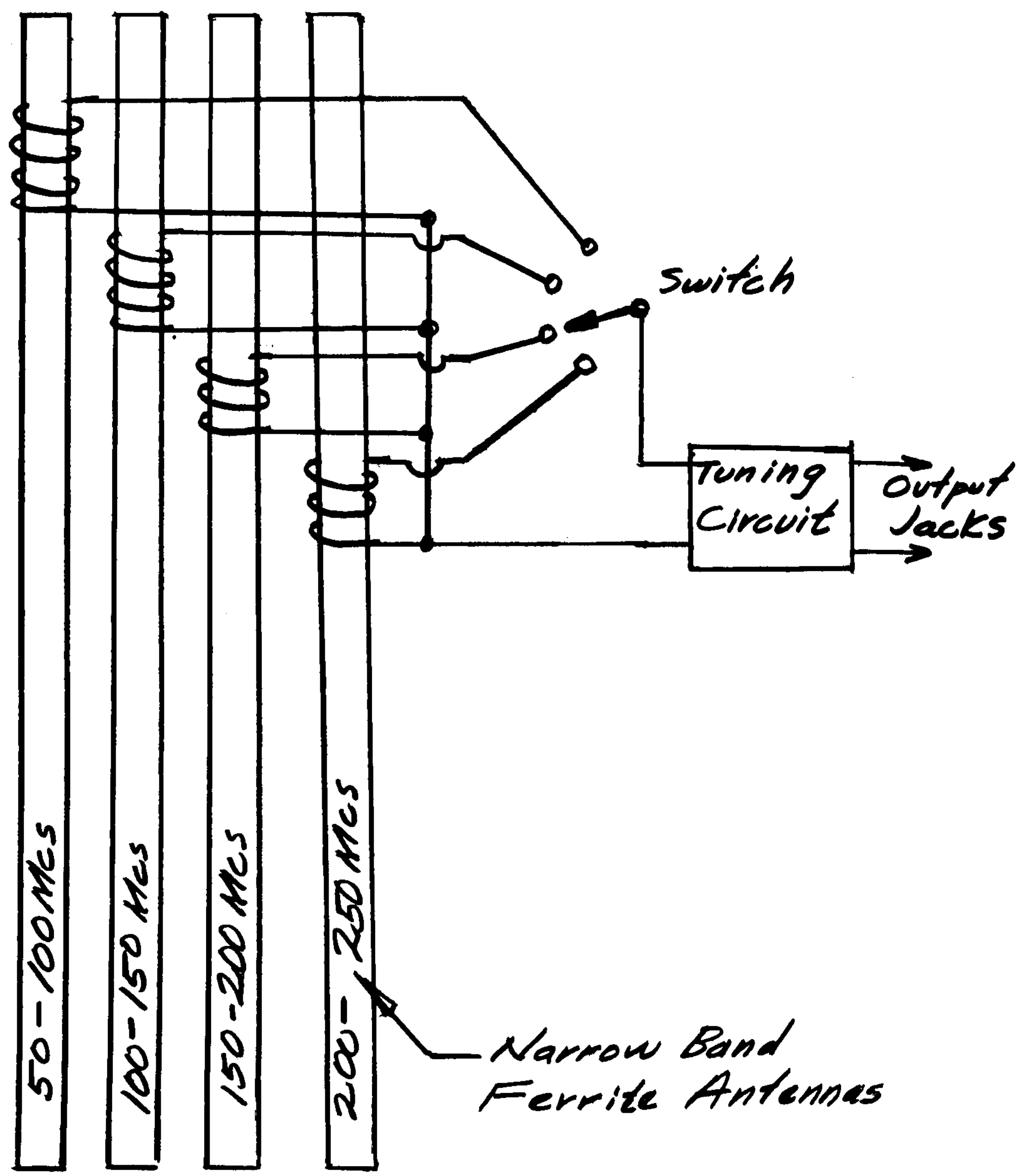

FIGURE 2

NARROW BAND UNIT

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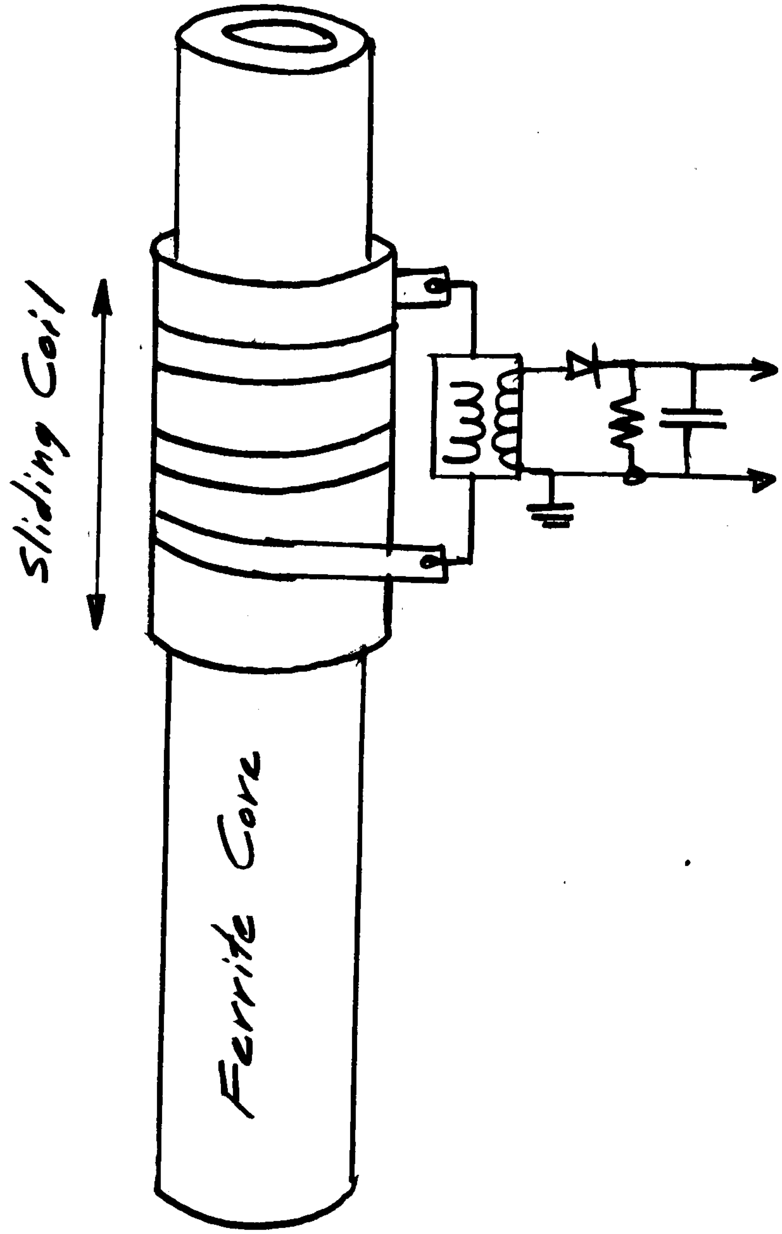

FIGURE 3

NARROW BAND UNIT WITH SELF-CONTAINED TUNING FEATURE

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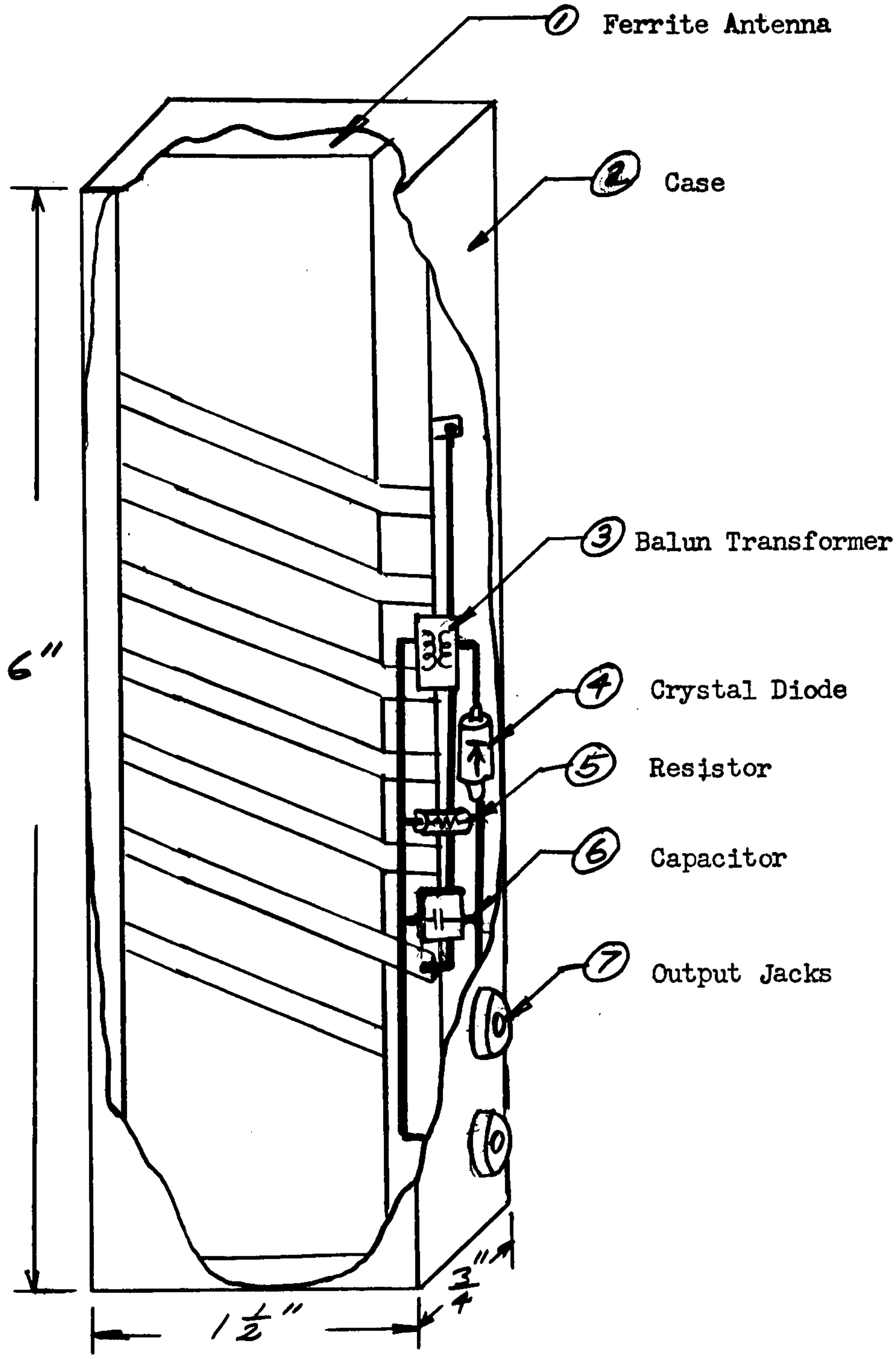

FIGURE 4

WIDE BAND UNIT

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3. PHASE B: A Proposal to Study the Use of Ferrite Antennas in the 3 to 30 Mcs Range

I. Introduction

Interest has been expressed in a 10-watt transmitting antenna of small size, good gain, and high efficiency for operation in a frequency region of 3 to 30 mcs. [redacted] 25X1 suggests that a similar antenna designed for the 3 to 30 mc frequency band would meet the requirements very adequately.

The large relative permeability which can be achieved in ferrite materials simultaneously with large resistivities allow an antenna to be coupled to a radiating magnetic field more effectively than do conventional ferromagnetic materials in which the radiating fields are strongly attenuated by the large conductances. Ferrites also offer the possibility of coupling an antenna effectively to radiating electric fields by virtue of their large relative dielectric constants. The losses in the ferrite materials can be made low over certain frequency bands by a judicious choice of material and process parameters. These properties of ferrites permit antennas of small size, good gain, and high efficiency to be designed by incorporating these materials.

Still another unexpected advantage results from the use of ferrite antennas. Accepted theory, such as developed by Chu[1], indicates that a reduction in antenna size necessarily reduces its bandwidth for a fixed gain. The [redacted] 25X1 antenna has a good gain over a large frequency band and thereby violates the accepted theory. Therefore, ferrite antennas offer not only the possibility of antennas of small size, good gain, and high efficiency, but also of broad bandwidth.

---

1 - "Physical Limitations of Omnidirectional Antennas", L.J. Chu, Journal of Applied Physics, 19, No. 12, December 1948.

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II. Study Program Objectives

A study program is being proposed as the first step in the development of a satisfactory antenna for the 3-30 mc range because it is believed that this procedure will be the most economical and give the greatest probability of success in the long run. The study program will have the following objectives:

(1) Provide a sound explanation as to the broad bandwidth of the present VHF antenna by theoretical study and experimental confirmation.

(2) Determine optimum material parameters and circuit configuration.

(3) Evaluate any presently available materials in the light of the results of the theoretical study to determine their applicability to this problem.

(4) Provide an accurate evaluation of further work necessary to completely develop a satisfactory antenna.

At the termination of the study program, there should be available all the necessary data to evaluate the technical and economical aspects of proceeding to the final phase of a ferrite antenna development program.

III. Present Status

(a) Antennas

[redacted] has acquired valuable knowledge and experience in the development of ferrite antennas as witnessed by the following achievements: 25X1

(1) Ferrite antennas have been incorporated in production models [redacted] since 1951. Their small size and good gain make ferrite antennas particularly well suited for portable and table model radios.[2,3] 25X1 25X1

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2 – [redacted] 25X1

3 –

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[redacted] 25X1

(b) Materials

[redacted] 25X1

[redacted] has been engaged in basic research of ferrite properties since 1951. 25X1 This sub-section cooperated in the development of materials for the ferrite antennas developed by [redacted] The knowledge, facilities, 25X1 and materials afforded [redacted] by this group is an important 25X1 asset in implementing this proposed study. It is the collective opinion of informed personnel in this group that ferrite materials are presently available in the 3 - 30 mcs frequency band suitable for a 10-watt transmitting antenna. Ferrites with a relative permeability of 20 and with a material "Q" of 50 are available.

IV. Need for a Study

If a small, efficient ferrite antenna is to be designed for operation at 3 - 30 mcs, a careful preliminary study must be made. [redacted] 25X1

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reasons to believe otherwise. For example, such material parameters as permeability "μ", dielectric constant "ε", and the relative losses "Q" are known to be frequency dependent. Therefore, a knowledge of how these material parameters affect the gain, efficiency, and bandwidth of the antenna is needed before one can choose or fabricate, if possible, the proper materials for operation in the desired frequency band.

The behavior of the material is not the only consideration. The design of the present antenna might be improved upon. The gain of this antenna was found to be a function of such parameters as the shape of cross-section of the ferrite rod and the ratio of its length to its cross-sectional area. An analysis of the antenna would enable the geometry of the present design to be optimized.

Furthermore, different antenna configurations might prove even more desirable. Thus, if the omnidirectional property of the antenna could be sacrified for greater gain, a directional antenna or array could be devised advantageously.

Thus, the ferrite antenna holds promise of fulfilling the need for a small, efficient transmit-receive antenna at 3 - 30 mcs, but a careful preliminary study appears wise before embarking upon a more costly developmental program.

V. Proposed Study 25X1

(a) Investigation of Broadband Characteristics

One of the most attractive explanations of the broadband characteristics of the ferrite antenna [redacted] postulates a frequency dependent "μ" and "ε" such that the material itself 25X1 serves as an automatic tuner. The physical limitation on an antenna derived by Chu cannot be given the popular interpretation of gain-bandwidth product if the antenna has an automatic tuner included as part of the antenna.

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It is proposed to study the broadband property of the ferrite antenna by approximating the antenna with a magnetic dipole imbedded in a mass of ferrite of some convenient geometry; e.g., a magnetic dipole situated at the center of a ferrite sphere. The ferrite will be assumed to have zero conductance, and real values of "μ" and "ε" which are frequency dependent. The frequency dependence of "μ" and "ε" required to make the radiation impedance purely resistive and of constant value will be calculated. The resulting frequency dependence of "μ" and "ε" will be compared with their measured behavior in the 45 to 250 mcs band. If the calculated behavior is approximated by the measured behavior, the frequency dependence of "μ" and "ε" will be considered a satisfactory explanation of the broadband phenomenon and can serve as a material specification for the choice or development of a ferrite suitable for use in the 3- 30 mcs band.

Since the measured frequency dependence of "μ" and "ε" are not readily obtainable, it is expected that these measurements will, of necessity, be included as a part of this study.

The mathematical expressions derived during the analysis of the magnetic dipole might suggest an equivalent circuit for the antenna which would simplify further analyses. Or, if the dipole analysis yields mathematical expressions too unwieldly to handle expediently, a reasonable equivalent circuit with frequency dependent components might be postulated. If the material parameters "μ" and "ε" can be associated with the circuit components, the radiation impedance can again be required to be constant and purely resistive in order to find the required frequency variation of the parameters for broadband operation.

If the measured frequency variations of "μ" and "ε" are not sufficient to explain the broad bandwidth of the ferrite antenna, other possible explanations can be investigated. For example, [redacted] has suggested the 25X1

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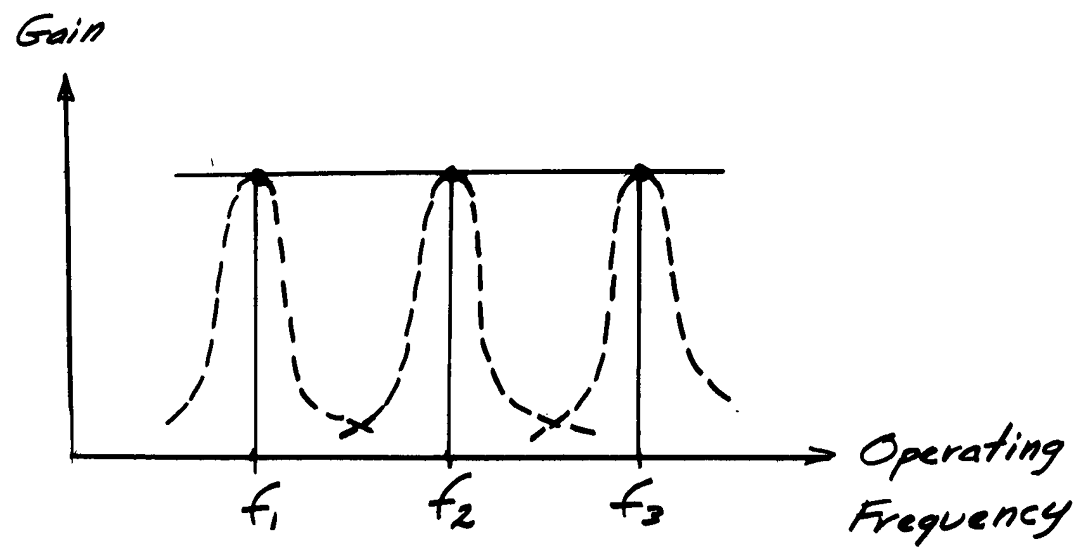
possibility that multiple modes existing on the helix interact with modes within the ferrite to produce the broadband phenomena. If such were the case, an analysis would result in important design formulae and material specifications applicable to the 3 - 30 mcs band.

(b) Investigations of the Antenna Gain

The accepted interpretation of the theory developed by Chu indicates that the gain of an omnidirectional antenna can be increased without bound, but that the bandwidth necessarily decreases very rapidly as the gain increases. The accepted interpretation is no longer valid for frequency dependent "μ" and "ε". If the values of "μ" and "ε" were constant, the antenna would indeed have a narrow bandwidth. But a frequency dependent "μ" and "ε" can introduce a broadband antenna. The broadband phenomena can be pictured as follows. The narrow bandwidth of Chu tracks the operating frequency so that the antenna ideally always operates at resonance. See Figure 5. In this case, the gain can be made large without limit without reducing the bandwidth.

FIGURE 5



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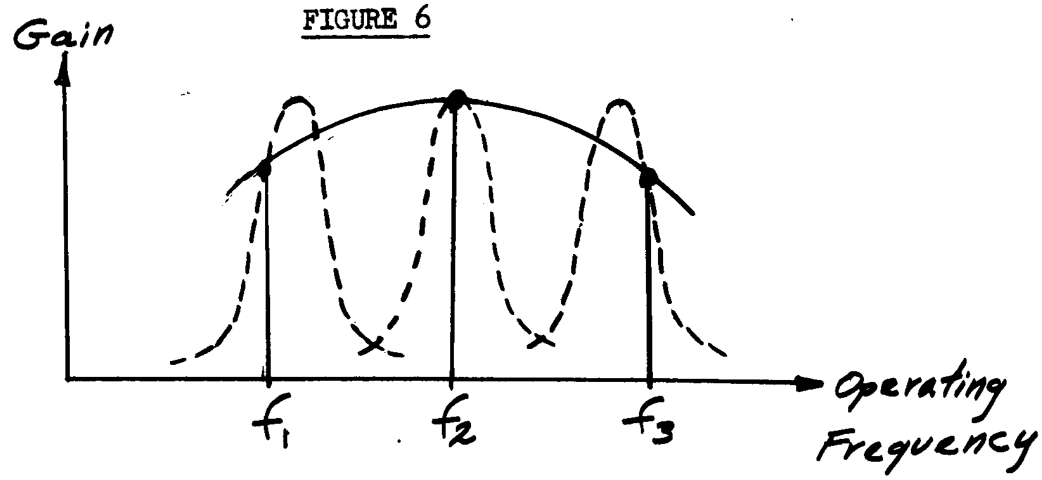
If the frequency dependence of "μ" and "ε" is not quite ideal, however, the narrow band as given by Chu does not quite track the operating frequency. See Figure 6.

FIGURE 6



Here the bandwidth is a function of the gain. The maximum gain, consistent with the actual frequency variation of "μ" and "ε" and the desired bandwidth, will be calculated. If the actual gain is significantly different from the calculated maximum gain, attempts will be made to increase the gain.

If warranted, the following analysis of gain will be pursued. The antenna will be approximated by an infinitesimal magnetic dipole situated on the axis of symmetry of a right circular ferrite cylinder having a fixed cross sectional area with axial symmetry, but otherwise arbitrary in shape. The length of the ferrite cylinder will also be held fixed. The conductivity, permeability, and dielectric constant of the ferrite will be assumed constant since a fixed operating frequency is assumed. Then the ratio of cross-sectional area to cylinder length and the cross-sectional geometry will be chosen such as to maximize the gain.

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(c) Antenna Efficiency

The conduction and hysteresis losses occurring within the ferrite material decrease the antenna efficiency. The losses are a function of frequency. It will be necessary to measure the losses of currently available materials to determine if any of them are suitable for use in the desired frequency region.

If the magnetic hysteresis losses are large for ferrites having a large enough relative permeability to achieve the desired gain, another antenna design might be required for high efficiency. In such a case, it is proposed to investigate the merit of a combination dielectric-ferrite antenna at the stated frequencies. The dielectric ferrite antenna as presently conceived will be an untuned antenna coupling to the electric field much in the same manner [redacted] VHF ferrite antenna couples to the magnetic field. A material will be chosen having a high dielectric constant to achieve the high gain. Then a ferrite circuit would couple the field in the dielectric to a conductor. The ferrite could be of rather low permeability since the antenna gain is achieved primarily through the large dielectric constant. The low permeability permits the magnetic losses to be low also. It is not known that such an antenna would be broadband. 25X1

(d) Antenna Characteristics

Although the proposed work is principally a study of the plausibility of a ferrite antenna at the interested frequencies, it is conceivable that a few preliminary antenna designs will result and be tested. The gain, efficiency, radiation impedance, and power handling capabilities of all such antennas will be measured.

(e) Reports

Monthly progress letters, quarterly reports, and a final report will be submitted to the contracting agency to report on the progress and results of the investigations performed in Phase B.

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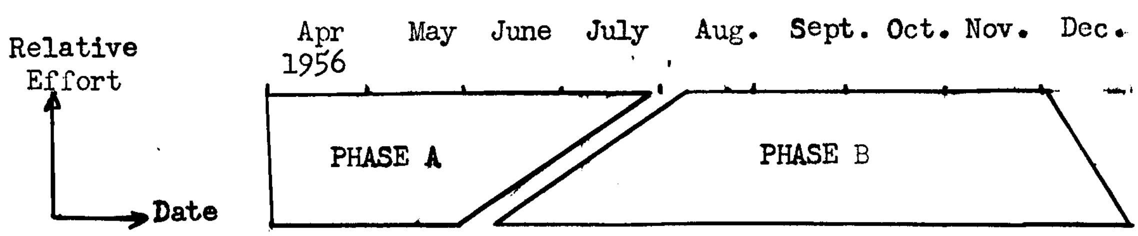
When Phases 'A' and 'B' are running concurrently, one monthly progress letter will cover both Phases. The more inclusive report will replace all other reports when more than one report falls due on the same date.

4. Manpower Requirements and Work Schedules

The ferrite antenna development program is planned to extend over a 39-week period. Phase A will be emphasized for the first 13 weeks and Phase B for the remaining 26 weeks. A transitional period of about 8 weeks will exist during which work on Phase A will be concluded, while work on Phase B is initiated. See Figure 7.



The manpower requirements are summarized in Table I.

TABLE I

	PHASE A	PHASE B
Engineers	1	1-1/2
Laboratory Assistants	1	1
Consultants	1/2	1/4

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